AFRL-VS-HA-TR-98-0092

STUDIES OF IONOSPHERIC PLASMA ELECTRODYNAMICS

R.A. Heelis

University of Texas at Dallas
William B. Hanson Center for Space Science
P.O. Box 830688, MS FO 22
Richardson, TX 75083-0688

May 1996

Scientific Report No. 3

1 March 1995-28 Feb 1996

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
29 Randolph Rd
AIR FORCE MATERIEL COMMAND
Hanscom AFB, MA 01731-3010

This Technical Report has been reviewed and is approved for publication.

William S. Borer
William S. Borer
Contract Manager

Frank A. Marcos
Frank A. Marcos, Acting Chief
Ionospheric Models Branch

This report has been reviewed by the ESC Public Affairs Office (PA) and is releasable to the National Technical Information Service.

Qualified requestors may obtain additional copies from the Defense Technical Information Center (DTIC). All others should apply to the National Technical Information Service (NTIS).

If your address has changed, if you wish to be removed from the mailing list, of if the address is no longer employed by your organization, please notify AFRL/VSOS-IMA, 29 Randolph Rd., Hanscom AFB, MA 01731-3010. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned. When no longer needed, destroy this document by any method that will prevent reconstruction of its contents.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1996	Scientific, Interim, Mar 1995-Feb 1996

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Studies of Ionospheric Plasma Electrodynamics; Scientific Report No. 3	Contract F19628-93-K-0008 PR 2310 TA GL WU AA
6. AUTHOR(S) Roderick A. Heelis	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) William B. Hanson Center for Space Sciences University of Texas at Dallas P.O. Box 830688 M/S FO22 Richardson, TX 75083-0688	8. PERFORMING ORGANIZATION REPORT NUMBER UTD-AR-3-630150
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFRL/VSBP 29 Randolph Rd Hanscom AFB, MA 01731-3010 Contract Manager: William Borer	10. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-VS-HA-TR-98-0092
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This research effort has been focused primarily on the characterization of large scale plasma patches in the high latitude ionosphere and on the irregularities in density and velocity that are associated with them.

Ionization patches are distinguished by elevation in the ion concentration above the nominal background polar cap values. Thus, any structure associaed with them is associated with high number densities and thus is more effective in producing radio scintillation. Indeed, it is well known from event studies that patches are a seat for scintillations. What is not known, or consistently derived, is a morphological description of the seasonal and spatial location of these patches and the associated spectral characteristics of the density irregularities. To accomplish this goal we have first sought an objective criterion for the definition of a patch that can be used over an extensive satellite data base. Then we seek to describe the observed irregularities associated with patches.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Ionosphere Structure Convection	12
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNL

TABLE OF CONTENTS

STUDIES OF IONOSPHERIC PLASMA ELECTRODYNAMICS

Introduction

During this contract period our research effort has been focused primarily on the characterization of large scale plasma patches in the high latitude ionosphere and on the irregularities in density and velocity that are associated with them.

Ionization patches are distinguished by elevations in the ion concentration above the nominal background polar cap values. Thus any structure associated with them is associated with high number densities and thus is more effective in producing radio scintillation. Indeed it is well known from event studies that patches are a seat for scintillations. What is not known, or consistently derived, is a morphological description of the seasonal and spatial location of these patches and the associated spectral characteristics of the density irregularities. To accomplish this goal we have first sought an objective criteria for the definition of a patch that can be used over an extensive satellite data base. Then we seek to describe the observed irregularities associated with patches.

1. Characterization of Polar Cap Patches

Characterization of an ionization patch requires a definition of the background density, a definition of spatial gradients defining the patch edge and a definition of the magnitude of a density enhancement that constitutes a patch. To accomplish this task we applied short wavelength filters to define only a background level and then arbitrarily specified edge gradients that define a patch. Figure 1 shows the distribution of patches assuming edges are defined as 40% increases from the background level in 140 km or less. We note that the number of observed patches depends critically on the magnitude of the patch enhancement. Most important is to note that enhancements of a factor of 10 or more above the background are extremely rare, occurring less than 1% of the time. For significant enhancements of 100% of the background we find a preferred scale size for patches as shown in figure 2. Finally we note that, as discovered previously, patches appear predominantly in the winter polar cap and in a preferred longitude region corresponding in the northern

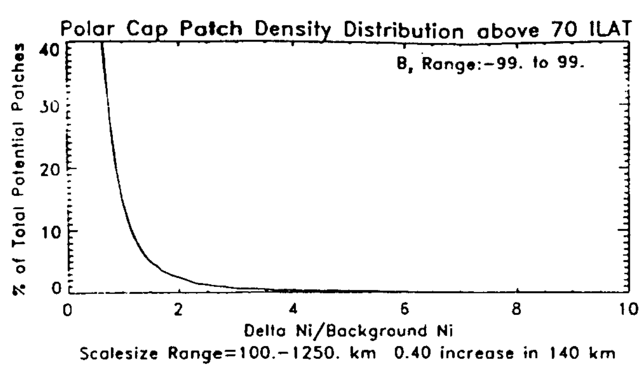

Figure 1. Percentage of northern hemisphere density enhancements larger than a given value.

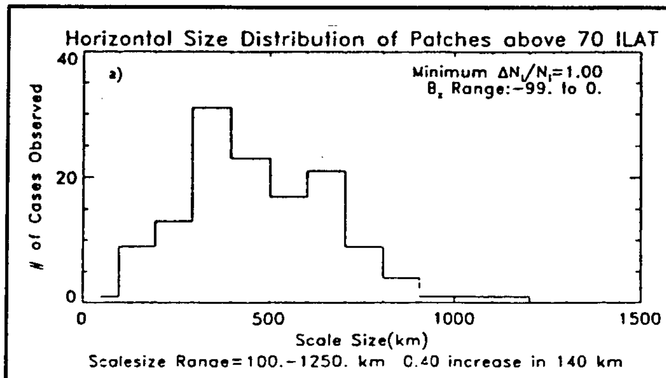

Figure 2. Scale size distribution of observed patches.

hemisphere to the sunward most excursion of the cusp. In addition to confirming previous work on the location of patches it is also consistent with recent modeling efforts that use a time dependent convection pattern to selectively draw high density plasma from the plasmasphere into the polar cap.

Having identified ionization patches, we are able to examine the properties of structures on the edges of a patch. Our investigation of density and velocity structures associated with polar cap ionization patches show that patches are usually regions of enhanced structure at small scale sizes (1-3 km) Observations indicate the presence of structure on almost all patches regardless of their distance from the cusp, where they are thought to originate. The observed characteristics of structures are most easily explained by a stirring mechanism that results in an enhanced level of structure on both edges of the patch. The level of small-scale structure is an increasing function of the magnitude of the density gradients regardless of their sign with respect to the background flow. A slight shift toward larger spectral slopes for positive density gradients with respect to the flow suggests that there is a contribution from the ExB drift instability. Overall we notice that patches are distinguished by enhanced density but not by unusual spectral characteristics.

2. Ionospheric Convection for Northward IMF.

An important exercise in the development of an overall description of the ionospheric convection pattern involves the correct representation of features appearing during time of northward IMF. We note that sunward flow at the highest latitudes on the dayside of the dawn-dusk meridian is the dominant feature seen in large-scale convection signatures during northward IMF. But sunward flow at highest latitudes does not imply the existence of two reverse convection cells at highest latitudes.

Four distinct signatures exist during northward IMF; four-cell signatures are located primarily on the dayside of the noon-midnight meridian, two-cell signatures are located primarily on the nightside, three-cell signatures are located on both the dayside and the nightside of the dawn-dusk meridian, while one-cell signatures generally do not extend to the lowest-latitude range on the nightside. Of these signatures Bz/By provides a first order selection criterion for those signatures that occur on the dayside but does not provide such ordering for signatures that occur in the nightside. Figure 3 describes the large-scale characteristics that we have identified and their dependence on the IMF.

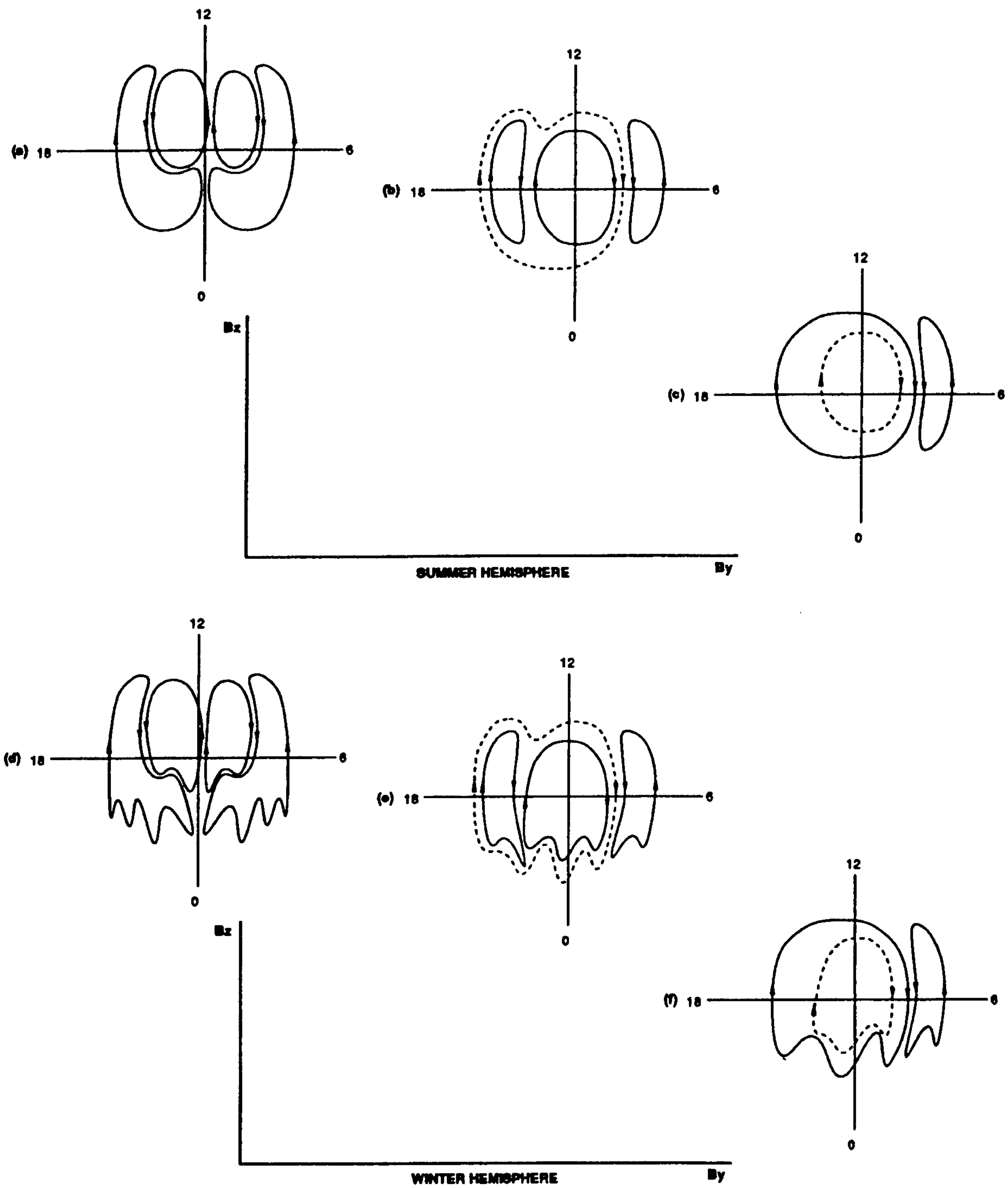

Figure 3. Schematic representations of the ionospheric convection pattern during periods of northward IMF

One cell signatures are attributed to lobe cell convection within the dominant dayside merging cell. These signatures are more likely to occur when Bx/By < 1.5, when By>Bx and during periods of less than average solar wind velocity. Three-cell signatures are attributed to dayside merging and lobe convection. These signatures are most likely to occur when the sign of By favors a negative potential dayside merging cell located on the duskside of the noon-midnight meridian and in the Bx favored hemisphere. In the four-cell signature the high-latitude cells are attributed to lobe convection. Under strongly northward IMF conditions, these signatures are more likely to form when the sign of By favors a positive potential high-latitude lobe cell located on the duskside of the noon-midnight meridian.

3. Topside Ionospheric Composition

Accurate interpretation of the total electron content measurements requires that we understand all factors affecting the ionospheric composition. Using data from the DMSP satellite in a circular orbit at 830-km altitude it is possible to characterize the composition at four different local times and to assess the impact of solar activity on the composition.

The first, most dramatic effect seen in the topside ionosphere is a longitudinal variation in the latitude composition and density profiles. These variations are most prominent at the solstices and indicate that both meridional and zonal winds in the Fregion play a role in redistributing the plasma in the topside. Figure 4 shows the ion composition as a function of longitude seen in the northern and southern hemisphere during northern summer. Note that in the summer hemisphere O+ is the dominant ion at 830 km altitude, while in the southern hemisphere H+ is dominant. In addition we notice that the density and composition asymmetry is greatest in the longitude region near 180 and is least in the longitude region near 300. This variation at 2100 hrs local time is consistent with the reinforcing and opposing roles of the meridional and zonal winds in each of these longitude regions.

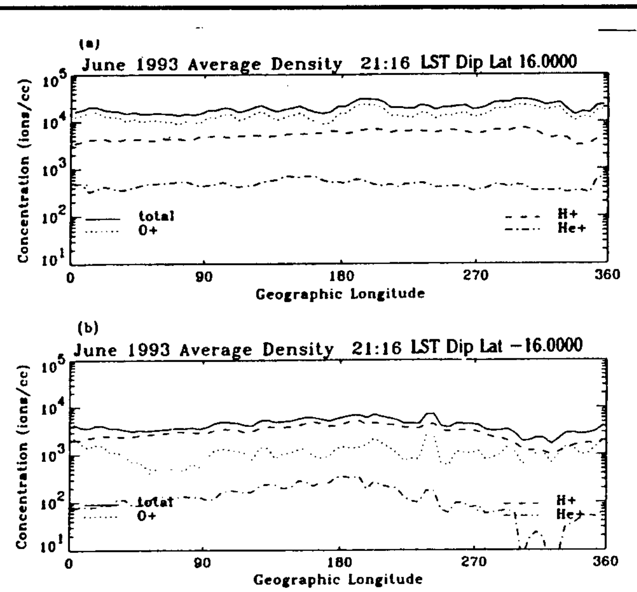

Figure 4. Longitudinal variations of composition observed during nighttime northern summer

Examination of the sensitivity of these results to solar activity is very interesting. At solar maximum we find that O+ is the dominant ion at all middle and low latitudes. In this case the action of neutral winds produces interhemispheric transport of O+ that tends to minimize the latitude asymmetry in the O+ distribution while maximizing that seen in H+. At solar minimum H+ is dominant above about 600 km altitude. In this case this species undergoes interhemispheric transport and thus the latitude asymmetry is minimized while O+ shows a large latitude asymmetry.

Publications

The work described above has been systematically published in the leading journals in our field. Titles and abstracts of this published work are given below.

Adaptive identification and characterization of polar ionization patches

W. R. Coley and R. A. Heelis

William B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson

Abstract. Dynamics Explorer 2 (DE 2) spacecraft data are used to detect and characterize polar cap "ionization patches", loosely defined as large-scale (>100 km) regions where the *F* region plasma density is significantly enhanced (≥ 100%) above the background level. These patches are generally believed to develop in or equatorward of the dayside cusp region and then drift in an antisunward direction over the polar cap. We have developed a flexible algorithm for the identification and characterization of these structures, as a function of scale-size and density enhancement, using data from the retarding potential analyzer, the ion drift meter, and the langmuir probe on board the DE 2 satellite. This algorithm was used to study the structure and evolution of ionization patches as they cross the polar cap. The results indicate that in the altitude region from 240 to 950 km ion density enhancements greater than a factor of 3 above the background level are relatively rare. Further, the ionization patches show a preferred horizontal scale size of 300–400 km. There exists a clear seasonal and universal time dependence to the occurrence frequency of patches with a northern hemisphere maximum centered on the winter solstice and the 1200–2000 UT interval.

Structures in ionospheric number density and velocity associated with polar cap ionization patches

Ö. Kivanç and R. A. Heelis
William B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson

Abstract. Spectral characteristics of polar cap F region irregularities on large density gradients associated with polar ionization patches are studied using in situ measurements made by the Dynamics Explorer 2 (DE 2) spacecraft. The 18 patches studied in this paper were identified by the algorithm introduced by *Coley and Heelis* [1995], and they were encountered during midnight-noon passes of the spacecraft. Density and velocity spectra associated with these antisunward convecting patches are analyzed in detail. Observations indicate the presence of structure on most patches regardless of the distance between the patch and the cusp where they are believed to develop. Existence of structure on both leading and trailing edges is established when such edges exist. Results, which show no large dependence of $\Delta N/N$ power on the sign of the edge gradient ∇N, do not allow the identification of leading and trailing edges of the patch. The $\Delta N/N$ is an increasing function of ∇N regardless of the sign of the gradient. The correlation between $\Delta N/N$ and ΔV is generally poor, but for a given intensity in ΔV, $\Delta N/N$ maximizes in regions of large gradients in N. There is evidence for the presence of unstructured patches that seem to coexist with unstructured horizontal velocities. Slightly smaller spectral indices for trailing edges support the presence of the E×B drift instability. Although this instability is found to be operating in some cases, results suggest that stirring may be a significant contributor to kilometer-size structures in the polar cap.

High-latitude ionospheric convection pattern during steady northward interplanetary magnetic field

J. A. Cumnock,[1] R. A. Heelis, and M. R. Hairston

W. B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson

P. T. Newell

Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland

Abstract. The DMSP F8 satellite's coverage of Earth's polar regions provides horizontal ion drift velocities along the dawn-dusk meridian at approximately 835 km altitude in each hemisphere during the ~100 min orbital period. We examine the ionospheric convection signatures observed by this spacecraft in the summer and winter hemispheres during periods when the interplanetary magnetic field (IMF) is directed northward for at least 45 min prior to the satellite entering the polar region and remains northward throughout the polar pass. These convection signatures can be readily categorized by the number of sunward and antisunward flow regions and by their potential distributions. Here we describe the most frequently identifiable and reproducible features of the convection pattern that exist during steady northward IMF conditions. In addition to IMF B_z, the influences on the convection pattern of the IMF $B_z/|B_y|$ ratio, season, latitude, and solar wind velocity are all considered. The ratio $B_z/|B_y|$ provides a first order organization of the signatures that occur on the dayside of the dawn-dusk meridian. Sunward flow at highest latitudes on the dayside of the dawn-dusk meridian is the dominant feature seen in the large-scale convection signature during steady northward IMF; however, sunward flow at highest latitudes does not imply the existence of a particular number of convection cells.

Longitude variations in ion composition in the morning and evening topside equatorial ionosphere near solar minimum

K. H. West and R. A. Heelis

W. B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson, Texas

Abstract. Ion composition data from the Defense Meteorological Satellite Program (DMSP) F10 have been averaged by geographic longitude and dip latitude for the months of June, September, and December 1993. The data were taken under near solar minimum conditions. Near 800 km at two fixed local times near 0920 hours and 2120 hours, and at all longitudes, significant variation in local time and season are found. Longitude variations are consistent with modulation of the F peak height by meridional and zonal neutral winds. The components of these winds parallel to the magnetic field lines act to raise and lower the height of the F peak and, additionally, at night, to modulate the plasma decay rate. Zonal winds were found to have significant effects in the longitude regions 150°E to 270°E and 300°E to 360°E, where the magnetic declination is significant. Under solstice conditions, the summer to winter meridional winds play a dominant role in regulating the F peak height, with the zonal winds enhancing or opposing the effects of the meridional winds at longitudes with significant magnetic declination. Zonal winds dominate the regulation of the F peak height near equinox, when the meridional winds are fairly symmetric about the dip equator. The longitude variations are most clearly seen in the O^+ and H^+ concentrations when O^+ is the dominant ion and is in equilibrium with H^+. These conditions were found during the daytime during all seasons. H^+ is frequently the dominant ion near 800 km, and at night, the longitudinal variations clearly seen in the O^+ concentrations were not as easily seen in the H^+ concentrations due to the larger scale height of H^+.